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Mode of emplacement of Archean komatiitic tuffs and flows in the Selkirk Bay area, Melville Peninsula, Nunavut, Canada

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ABSTRACT

The 2.97 Ga Prince Albert greenstone belt (PAGB) of Melville Peninsula (Nunavut, Canada) contains multiple komatiitic flows and laterally extensive units of komatiitic tuff in the Selkirk Bay area. These units are serpentinized, chloritized, amphibolitized, and less commonly, carbonate altered. The tuffs retain element abundances typical of Al-undepleted komatiites, identical to the associated komatiitic flows, indicating that the tuffs and flows are comagmatic. The flows exhibit excellent textural preservation with well-developed upper spinifex and lower cumulate zones typical of differentiated komatiite flows. However, the tuffs do not preserve primary microscale textures and are fine-grained and largely massive to planar-laminated. This, coupled with their extensive nature (up to 10 km laterally; up to 10 m thick vertically), lack of gradational contacts with komatiitic flows, and their komatiitic mineralogical and chemical composition support a pyroclastic origin, deposition via eruption-fed fallout and mass flow, and subaqueous deposition during intervals characterized by lower rates of effusive volcanism. The low volatile content of the komatiitic magma, indicated by lack of vesicles in komatiitic flows and the lack of scoriaceous lapilli in the tuff, suggests an origin through phreatomagmatic pyroclastic eruptions. The Selkirk Bay komatiitic lavas and tuffs have liquid compositions with up to 30 wt% MgO, consistent with their derivation from a high magnesium komatiitic parental magma. There is evidence for up to 15% crustal contamination, which is also supported by slight enrichments in the LREE and Th relative to Nb. Major and minor elemental trends are indicative of olivine being the dominant liquidus mineral during early crystallization.

Komatiitic flows of the PAGB were erupted onto massive to pillowed basalt where they formed thick, channelized, massive, undifferentiated flows flanked by spinifex-textured sheet/lobate flows. Synvolcanic structural basins and down-faulting are considered responsible for flow channelization and also controlled the deposition of local, framework-supported, ultramafic mass flow deposits and localized deposits of felsic volcaniclastic rocks. The komatiitic tuffs occur at two stratigraphic intervals indicating that they are a product of at least two pyroclastic eruptions. The uppermost strata document a change to a more mafic-dominated lava sequence interlayered with both differentiated and undifferentiated komatiitic flows, which are overlain by thick deposits of felsic volcaniclastic rock.

1. Introduction

Komatiitic rocks are rare ultramafic volcanic and subvolcanic rocks that occur predominantly in Archean and Paleoproterozoic greenstone belts (Arndt et al., 2008). They contain >18% MgO, have olivine spinifex-textures or are related to rocks that have spinifex textures, and have low silica contents and very low incompatible element abundances. The high eruption temperature of komatiites (1640 °C or more) and their very low viscosities (0.1–10 Pa s^{-1}) (Arndt and Nisbet, 1982; Huppert et al., 1984; Huppert and Sparks, 1985) have resulted in their emplacement mainly as lava flows (e.g., Viljoen and Viljoen, 1969; Huppert and Sparks, 1985), less commonly as shallow-level sills (e.g., Houlé et al., 2008; Heggie et al., 2012), and more rarely by pyroclastic processes (e.g., Stiegler-Thompson et al., 2010). Arndt et al. (2008) subdivided komatiitic rocks into four main groups based on geochemical attributes: *group 1* 'Barberton-type' Al-depleted komatiites (ADK), which are

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depleted in Al relative to Ti ($Al_2O_3/TiO_2 < 15$), and are depleted in HREE relative to LREE; *group 2* 'Munro-type' Al-undepleted komatiites (AUK), have near chondritic Al_2O_3/TiO_2 ($\sim$20) and flat REE patterns; *group 3* 'Gorgona-type' Al-enriched komatiites (AEK), are enriched in Al relative to Ti ($Al_2O_3/TiO_2 > 30$) and LREE-depleted, and *group 4* 'Karasjok-type' Fe–Ti enriched komatiites (TEK), which are enriched in Fe and Ti relative to Al and are strongly depleted HREE (Nesbitt and Sun, 1976; Sun and Nesbitt, 1978; Nesbitt et al., 1979; Barnes and Often, 1990).

Variations in texture, internal architecture, thickness, and areal extent of komatiitic lava depend on a variety of factors such as magma viscosity, eruption rate, cooling rate, slope, and underlying topography (e.g., Huppert and Sparks, 1985; Lesher et al., 1984; Dann, 2000). Their extremely low viscosity and relatively high density imply that, when erupted, they likely formed fast-flowing, extensive flows characterized by low aspect ratios (Viljoen and Viljoen, 1969). However, restriction of flows, possibly through ponding (Dann, 2000) or channelization within topographic lows (Lesher et al., 1984), could cause flow inflation due to repeated lava pulses and result in the formation of thick flows. An important factor that dictates their mode of emplacement is substrate nature (coherent material, e.g., lavas, and incoherent material, e.g., volcanoclastic/sediments) of the footwall rocks to ultramafic magmas (Houlé et al., 2008; Heggie et al., 2012).

Komatiitic flow facies have been subdivided into lithofacies based on the degree of internal differentiation and degree of olivine accumulation (Lesher et al., 1984; Lesher, 1989). Thick, undifferentiated, cumulate komatiite flows like those at Kambalda (Western Australia) are interpreted to have formed in channels through which lava flowed rapidly. Thin, differentiated, non-cumulate komatiite flows like those in Munro Township (Ontario), which are typical of many komatiitic successions, are thought to represent lateral or distal facies that spread out from a central feeder or channel. However, undifferentiated, cumulate and differentiated spinifex-bearing komatiites also occur as high-level, syn-volcanic sills (e.g., Houlé et al., 2008; Rosengren et al., 2007).

In contrast to lava flows and sills, descriptions of komatiitic volcaniclastic rocks are sparse in the literature. However, occurrences have been described in many komatiitic-bearing greenstone belts around the world, including the 3.5–3.2 Ga Barberton greenstone belt, South Africa (Lowe, 1999; Stiegler-Thompson et al., 2011), the 3.0 Ga Lumby Lake – Steep Rock Group, Canada (Schaefer and Morton, 1991), the 3.0 Ga Meekatharra–Wydgee belt, Australia (Barley et al., 2000), the 2.7 Ga Abitibi belt, Canada (Gélinas et al., 1977; Champagne, 2004), and the 2.0 Ga Karasjok belt, Finland (Saverikko, 1983, 1985; Barnes and Often, 1990). In these occurrences, the komatiitic volcaniclastic rocks have been interpreted to result from either the erosion of komatiitic lava flows (post-eruptive epiclastic deposits), quenching of subaqueous extrusive lava and subsequent re-deposition (syneruptive hyaloclastite deposits), or pyroclastic eruption and deposition (primary pyroclastic deposits).

The degree of the role of volatiles (e.g., water) in the formation of komatiites has been widely debated over the past decades (anhydrous: e.g., Arndt et al., 1998, 2008; hydrous: Parman et al., 1997, 2004; Fiorentini et al., 2012). Consequently, the existence and formation of komatiitic pyroclastic eruptions are controversial. The volatile content of komatiite liquids is presumed to be too low to result in magmatic pyroclastic eruptions, where fragmentation is driven by rapid vesicle growth through diffusion and decompression (Sparks, 1978; Lowe, 1999; Arndt et al., 2008); the latter, in particular, can result in the instantaneous expansion of magmatic volatiles leading to magma fragmentation (Cashman et al., 2000). Thus, assuming komatiitic magmas contain <1 wt% H_2O, explosive magmatic pyroclastic eruptions are not possible except, perhaps, under special circumstances. However, pyroclastic fragmentation can also result from the instantaneous and explosive expansion of vaporized water when it interacts with magma, as in hydrovolcanic, phreatomagmatic pyroclastic eruptions (Morrissey et al., 2000). Key features of komatiitic magmas such as their very low viscosity and high eruption temperature are particularly favorable for phreatomagmatic pyroclastic eruptions (Lowe, 1999), and pyroclastic deposits produced through explosive hydrovolcanic processes arguably should be more common.

Key criteria in the recognition of hydrovolcanic pyroclastic deposits include the type and shape of particles: accretionary lapilli, blocky and equant to drop-like, mossy-like aggregates and plate-like shards, some with broken bubble walls, intact crystals, and crystal shards along with accessory and accidental lithic clasts (Morrissey et al., 2000). Violent phreatomagmatic eruptions are characterized by extensive deposits of fine ash-sized tephra (<2 mm in size) (Morrissey et al., 2000). Komatiitic pyroclastic deposits should also display bedforms and characteristics that are typical of falls (fallout, water-settled fallout) and/or mass flows (eruption-fed mass flows and density currents); as well, they must have geochemical characteristics of komatiites (e.g., high MgO, Ni, and Cr).

In this contribution, we present new volcanological and geochemical data based on detailed geological mapping of a Mesoarchean komatiitic succession in the Selkirk Bay area within the Prince Albert greenstone belt (PAGB) in the western part of Melville Peninsula of Nunavut (Canada). The aims of this investigation are: (1) to document the komatiitic volcanic facies (including lava flows, volcaniclastic deposits, and syn-volcanic sills) and their geochemical characteristics, (2) to provide a volcanic reconstruction prior to, during, and after-ultramafic volcanism, (3) to present evidence to support a primary pyroclastic origin for the komatiitic volcaniclastic rocks and their crucial role in the reconstruction of the depositional setting of this volcanic succession, and (4) argue that water depth is a controlling factor in komatiitic hydrovolcanic eruptions, thereby explaining the apparent paucity of komatiitic pyroclastic rocks.

2. Geological setting

2.1. Prince Albert greenstone belt

The komatiitic rocks in the Selkirk Bay area are part of the Prince Albert greenstone belt (PAGB) of the Rae Province and were first recognized by Tom Frisch and co-workers during a Geological Survey of Canada bedrock mapping program in the 1970s (Frisch and Jenner, 1975; Frisch and Goulet, 1975). The PAGB comprises Mesoarchean supracrustal rocks flanked by granitic intrusions (Figs. 1 and 2). The PAGB volcanic-sedimentary succession has been metamorphosed to upper greenschist to amphibolites facies (Frisch, 1982; Machado et al., 2011); however, for succinctness the "meta" prefix has been omitted when describing rock types in the area.

The succession has been divided into three informal formations based on field relationships, lithological association, mineralogy, and textural preservations (Machado et al., 2011; Fig. 2). Stratigraphically, the basal *Adamson River formation* is composed of a lower section of mafic to intermediate subaqueous volcanic rocks with lesser ultramafic flows/sills and volcaniclastic rocks and an upper section of felsic to intermediate volcanic, volcaniclastic and clastic sedimentary rocks. The overlying *Triangle Lake formation* is dominated by mafic to intermediate volcanic rocks intercalated with chert-magnetite banded iron-formation, and lesser felsic to intermediate volcaniclastic, clastic sedimentary rocks, and ultramafic intrusive rocks. The uppermost volcano-sedimentary *Mackar formation* uncomformably overlies the *Triangle Lake formation*, and is characterized by a polymictic conglomerate containing iron